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Effect of Pre-Shelling Treatment on Physical and Mechanical Properties of Cashew Nut

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Abstract. This study was conducted to investigate the effect of roasting in hot oil on physical and mechanical properties of large (26-35mm), medium (23-25mm) and small (18-22mm) cashew nuts at moisture content of 7.00% w.b. The physical properties considered were length, width, thickness, geometric mean diameter, sphericity, true density, bulk density, porosity, mass, and coefficient of friction. The mechanical properties considered were, rupture force, deformation at rupture point, energy used for rupture and young modulus determined from compression test carried out in three major direction of loadings. It was observed that all the dimensional characteristics, mass and densities of cashew nuts before roasting were significantly different ($P < 0.05$) from after roasting. The pre-treatment has significant effect on coefficient of friction of cashew nut which has higher values on mild-steel and wood than other materials. The compression test results showed that the rupture force decreases with decrease in nut size for the three loading directions, however the transverse loading requires higher force than longitudinal and lateral loading for the three nut sizes. For large and medium size nuts, the highest rupture energy was needed in transverse loading direction, followed by lateral loading direction. The compression along the longitudinal direction has the least deformation for the three nut sizes. For the three nut sizes, the highest Young Modulus was exhibited in longitudinal loading direction followed by transverse loading direction.
Keywords: cashew nut, nut size, physical properties, coefficient of friction, rupture force, hot-oil roasting

1. Introduction

Cashew nut ((*Anacardium Occidentale Linn.*)) is one of the topmost edible tree nuts of the world. It consists of an outer shell (Epicarp), honey combed structure (Mesocarp), inner shell (Endocarp), Testa and Kernel. The Epicarp is greenish to pinkish brown depending on the degree of dryness. The mesocarp contains a natural resin, known commercially as a Cashew Nut Shell Liquid (CNSL). The CNSL is viscous and blister the human skin. The endocarp is hard but brittle. It protects the kernel from the Natural Resin. The epicarp, mesocarp and endocarp are known as pericarp [1- 2]. The art of processing cashew nuts is to shell them and extract the kernels 'whole' without breaking or damaging them. The methods employed by cashew nut farmers and manufacturers to shell the nuts have mainly included simple shelling devices, which usually are not efficient in their performances, and few cases of highly complex and expensive shelling machinery,

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usually through imports from Europe [3]. For the conditions in Nigeria which is among the largest producers of cashew nut in the world, there is a need of local shelling machinery with efficient performance and economical cost. Determining the physical and mechanical properties of cashew is of paramount importance to the development of the local shelling machinery.

Shelling of cashew nut to remove the kernel inside it is one of the major processes of the nut. Developing a device or machine to do this requires a comprehensive knowledge of the physical and mechanical properties of the cashew nuts and their mechanical behavior under pressure. Data of physical and mechanical properties of cashew nut such as length, width, thickness, geometric mean diameter, sphericity, true density, bulk density, porosity, mass, coefficient of friction, angle of repose, compressive loads (in lateral, longitudinal and transverse directions), energy at yield, deformation and young modulus are needed for designing shelling machines, harvesting, handling and storage systems for cashew nuts. Some of these data are also needed as input to mathematical model developed for prediction of force required to break the cashew nut.

Physical properties of cashew nuts have unique characteristics which make the nut to behave differently from mechanical or engineering materials. For many biological materials, their awkward or irregular shapes make difficult the analysis of their behavior. For the design of process equipment, cashew nut physical properties are needed. In controlling machines and processes, sensors are used. In developing such sensors, the information of the physical properties of the nut plays an important role. It also helps in storage, handling and quality difference detection during harvesting. Physical properties have also helped in designing many types of separation, grading and cleaning equipment [4]. In the design of storage structures, processing equipment and machines, the knowledge of physical properties make up an essential and important engineering data [5-6].

The behaviors of cashew nut in compression between two parallel plates is revealed by its mechanical properties. For textural analysis and good understanding of the fracture mechanics of the cashew nut, the investigation of mechanical properties is highly needed. The storage, processing techniques and shelling of the cashew nut all require its mechanical properties. In the design of machines for agricultural products, one of the essential considerations is to make sure that the stresses in machine elements do not go beyond the agricultural material's strength. To investigate damage caused by handling and harvesting of the vegetables, fruits, seeds, grains and cashew nut, the force deformation relationship of biological materials is being employed. The results or data of the behavior of an agricultural material from its test helps a great deal in the design of engineering equipment for its handling [6].

2. Materials and methods

Raw cashew nuts were procured from farm gate at Ilorin area of Kwara State, Nigeria at the average moisture content (MC) of 7.00% wet basis. Foreign materials such as stones, spoilt and immature nuts, leaves were separated from the nuts procured for use. The cashew nuts were graded into three different nut sizes using their axial dimensions: large (26-35mm), medium (23-25mm), and small (18-22mm) following the method developed by Balasubramanian [7]. 300 cashew nuts were selected from each nut size at random and the physical and mechanical properties of the nuts were determined before and after roasting in hot palm-kernel oil. The roasting time used was 90s [8] and the temperature used was 190°C-210°C [9-10].

The equipment used were: Carrera Precision Vernier Digital Caliper which measure to an accuracy of 0.01mm; oven (masterchef); Electronic Balance which measure to an accuracy of 0.0001g; measuring cylinder; thermometer; incline plane; stopwatch; a wire mesh basket designed to contain 25 nuts; universal testing machine (Testometric-AX model) which has a capacity from 0 – 25 kN and oil-bath of palm-kernel oil.

The cashew nuts were treated by frying in a bath of hot palm-kernel oil. The raw cashew nut was kept and used as the control. The cashew nuts were prepared and roasted as described below.
300 cashew nuts were selected from each nut size (i.e. large, medium and small). From these nuts, 25 nuts were selected, labeled and put in wire mesh basket which was divided into 25 compartment (see Figure 1). This was done in order to track each nut before and after roasting. The wire mesh basket was dipped into bath of hot oil at the temperature of 190°C-210°C for 90 seconds. This was done several times to complete the roasting of 300 nuts for each of the large, medium and small nut sizes. After roasting, the nuts were allowed to cool naturally for 18 hours [9, 11-12].

Fig. 1 Wire mesh basket

The following properties of the nuts were measured for the same nut before and after roasting in hot oil using standard methods [13] – length, width, thickness, geometric mean diameter, sphericity, true density, bulk density, porosity, mass and coefficient of friction on the following materials: glass, mild steel, galvanized steel, stainless steel, and ply wood. The mechanical properties were determined for only the roasted nuts.

(i) For each of the nuts, the principal axes were measured before and after roasting. The length-a of the nut was measured longitudinally. The width-b and thickness-c were measured perpendicular to the major axis of the nut. The geometric mean diameter (*GMD*) and sphericity (S_p) were determined by the following equations as documented by Mohsenin [13]:

$$GMD = (abc)^{1/3}; ---(1)$$

$$S_p = \frac{(abc)^{1/3}}{a} \times 100\% --- (2)$$

The dimensions were determined for all the nuts (300) of each nut size.

(ii) To determine the true density, the water displacement method was used. The mass of the nut was weighed and immersed into the measuring cylinder with known volume of water. The true density ρ_t of the cashew nut was determined by dividing the mass of the nut by the volume of water displaced when the nut was immersed in water (equation 3). For each of the nut size, true density of 60 nuts were determined.

$$\rho_t = \frac{mass}{volume} --- (3)$$

(iii) The mass of a cylinder was measure. Its volume was determined by filling it to the brim with water of known volume. The mass of the cylinder was determined again after it was filled with cashew nut in order to determine the mass of nut that fill the cylinder. The mass of the nut that fill the cylinder was divided by the volume of water that filled the cylinder to give the bulk density (ρ_b) [13]. This was repeated 60 times for each of the nut size.

$$\rho_b = \frac{weight\ of\ nuts\ in\ the\ container}{volume\ of\ the\ container} --- (4)$$

(iv) With known values of true density (ρ_t) and bulk density (ρ_b), the porosity (p) of the cashew nut was determined using the equation by Mohsenin [13].

$$p = \frac{\rho_t - \rho_b}{\rho_t} \times 100\% --- (5)$$

(v) The angle for the coefficient of friction for cashew nut was determined using the inclined plane method. This was done by placing each of the surfaces on the inclined plane, putting a cashew nut on it and then beginning to lift the inclined plane slowly and carefully until the nut just started sliding. The angle of inclination was measured by the calibrated protractor attached to the side of the inclined plane. Taking the tangent of the angle of inclination at which the cashew nut begins to slide on a surface gives the Coefficient of static friction according to the method described by Ogunsina & Bamgboye [9] and Dutta *et al.* [14]. For the ply wood the angle of inclination was determined in two directions. One was in the direction of the grain of the wood and the other was in the direction across the grain.

$$Coefficient\ of\ friction = \tan\theta\ --- (6)$$

For each of the nut size, 60 nuts were used to determine the coefficient of friction for each material.

(vi) The moisture content of the raw nuts was determined using ASAE standard 2003. The nuts were placed in moisture dishes and weighed before they were put in oven at 103 C for 6 hours. At the end of oven drying, the final weight of the moisture dishes and the nuts was weighed after reaching room temperature. The moisture content (wet basis) was determined by dividing the loss in weight due to oven drying by the initial weight [15].

$$Mc = \frac{M_l}{M_i} \times 100 ----(7)$$

Where Mc = moisture content; M_l = moisture loss; M_i = Initial weight of the sample.

(vii) Compression tests were carried out on the roasted cashew nuts between two parallel plates at a constant rate of 50 mm min^{-1} to determine the force at yield, energy at yield, deformation and Young's modulus at which the cashew nut would crack open without damaging the kernel within. The roasted cashew nuts were compressed in three different orientations (Figure 2): transverse (orientation 1), longitudinal (orientation 2), and lateral or natural (orientation 3). For each nut size, 60 nuts were selected and compressed in each orientation.

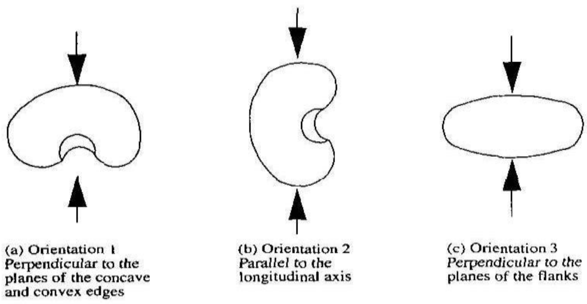

Fig. 2 Orientations of nut in relation to the direction of loading
(Source: Oloso and Clarke, (1993))

3. Results and discussion

Table 1 shows the physical properties of the cashew nuts before and after roasting in bath of hot oil. It should be noted that all the nuts were marked with labels, and their properties were measured before and after roasting. Table 2 shows the t-statistics of the paired sample t-test used to compare the properties before and after roasting. The table shows that the pre-treatment affects the properties of the cashew nut significantly. The negative t-value indicates an increase in the mean value of the properties of the nut when the nut was roasted. The positive t-value indicates a decrease. For all the large, medium and small nut sizes considered, it was observed that there was increase in the dimensions when the nuts were roasted. The increase in the dimensions of the nuts is attributed to the expansion of the shell as it came in contact with the hot oil. The dry shell ruptures and releases the cashew nut shell liquid (CNSL) in the oil bearing cells with high pressure, thus expanding the shell and reducing the weight because of the loss

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of CNSL. The increase in dimensions of the nut is contrary to the observations made by Balasubramanian [7] who carried out a similar work on raw cashew nut grown in India and Ogunsina & Bamgboye [9] who carried out similar work on cashew nuts grown in Nigeria. In their works, there was a decrease in the dimensions of the nuts which was due to the loss of moisture content and shrinkage during roasting. The difference in the observations was as a result of difference in the moisture content of the raw cashew nut that was roasted. In this work, the dry cashew nut was roasted (at 7.00%w.b.) while the moisture content of the cashew nut roasted in their work was greater than 12.0%w.b. The removal of the moisture present in the pericarp of the cashew nut during roasting led to the shrinkage of the nut. Table 2 shows that the difference in the means of length, width, thickness, geometric mean diameter and sphericity of raw and roasted nuts of all nut sizes are all significant ($P < 0.05$). The table shows that the true and bulk densities are influenced by the treatment. There was significant difference ($P < 0.05$) in the true and bulk densities of all nut sizes. The loss of CNSL of the cashew nut into the oil bath during roasting obviously account for the reduction in weight which in turn led to reduction in density of the nuts. The difference in the means of porosity of medium size nut is significant ($P < 0.05$), however there was no significant difference in the means of porosity of large and small nut sizes. The pre-treatment affects the coefficients of friction significant ($P < 0.05$), however for large size nuts on mild steel and stainless steel and medium size nuts on glass and galvanized steel, there was no significant difference in the means of the coefficients of friction. Tables 1 and 2 show that there was an increase in the coefficient of friction of medium and small size nuts. It was observed that the coefficient of friction on mild-steel and wood are higher than other materials for all the sizes of the nuts. The effect of the pre-treatment on the properties of the cashew nut can be further seen on Figure 3.

Table 1 Physical properties of cashew nuts before and after roasting

Properties		**Large**		**Medium**		**Small**	
	N	**Raw**	**Roasted**	**Raw**	**Roasted**	**Raw**	**Roasted**
Length (mm)	300	32.73(1.9)	33.56(1.9)	30.82(1.4)	31.66(1.5)	25.60(1.7)	27.32(1.3)
Width (mm)	300	24.97(2.0)	26.10(1.9)	23.46(1.2)	24.39(1.2)	20.44(1.3)	21.58(1.0)
Thickness (mm)	300	17.18(1.6)	18.74(1.6)	16.26(1.3)	17.68(1.2)	14.53(1.3)	16.14(1.1)
GMD (mm)	300	24.10(1.5)	25.39(1.4)	22.71(0.9)	23.88(0.9)	19.64(1.1)	21.18(0.9)
Sphericity (%)	300	73.71(3.6)	75.73(3.4)	73.80(3.6)	75.52(3.2)	76.85(3.5)	77.60(2.7)
True density (g/cm^3)	60	0.997(0.08)	0.727(0.09)	1.04(0.07)	0.733(0.08)	1.06(0.1)	0.685(0.09)
Bulk density (g/cm^3)	60	0.63(0.02)	0.467(0.03)	0.634(0.02)	0.462(0.02)	0.623(0.02)	0.400(0.03)
Porosity (%)	60	36.13(6.90)	34.77(9.99)	38.95(5.07)	36.19(7.7)	40.89(7.11)	40.62(9.5)
Mass of the nut (g)	60	7.81(0.94)	6.75(0.92)	5.80(0.59)	5.06(0.61)	3.82(0.67)	3.38(0.58)
COF							
Glass	60	0.38(0.09)	0.27(0.09)	0.26(0.07)	0.27(0.1)	0.29(0.07)	0.36(0.12)
Mild Steel	60	0.54(0.09)	0.52(0.09)	0.47(0.06)	0.54(0.07)	0.51(0.08)	0.59(0.08)
Galvanised Steel	60	0.46(0.08)	0.42(0.07)	0.44(0.05)	0.42(0.06)	0.44(0.06)	0.48(0.06)
Stainless Steel	60	0.45(0.08)	0.44(0.08)	0.43(0.06)	0.48(0.07)	0.43(0.07)	0.57(0.1)
Wood Along	60	0.46(0.09)	0.57(0.09)	0.44(0.07)	0.60(0.09)	0.46(0.07)	0.59(0.08)
Wood Across	60	0.47(0.07)	0.58(0.08)	0.44(0.07)	0.59(0.11)	0.46(0.06)	0.62(0.09)

GMD - Geometric mean diameter, COF – Coefficient of friction

Table 2 Effect of pre-shelling treatment on Physical properties of cashew nuts

t-statistics				
Properties	**df**	**Large**	**Medium**	**Small**
Length (mm)	299	-12.648*	-20.673*	-35.078*
Width (mm)	299	-16.492*	-22.082*	-21.200*
Thickness (mm)	299	-29.360*	-30.073*	-31.660*
Geometric mean diameter (mm)	299	-30.161*	-40.595*	-42.930*
Sphericity (%)	299	-16.936*	-16.544*	-6.550*
True density (kg/m^3)	59	23.470*	24.177*	32.364*
Bulk density (kg/m^3)	59	46.017*	55.824*	59.149*
Porosity (%)	59	1.387	2.366*	0.334
Mass of the nut (g)	59	14.052*	9.411*	14.554*
Coefficient of Friction				
Glass	59	6.641*	-0.128	-4.608*
Mild Steel	59	1.344	-5.624*	-5.922*
Galvanised Steel	59	2.558*	1.752	-3.966*
Stainless Steel	59	1.135	-4.506*	-9.681*

Wood Along	59	-6.464*	-11.193*	-9.141*
Wood Across	59	-9.430*	-10.684*	-11.041*

*t-Statistics are significant at 5% probability level

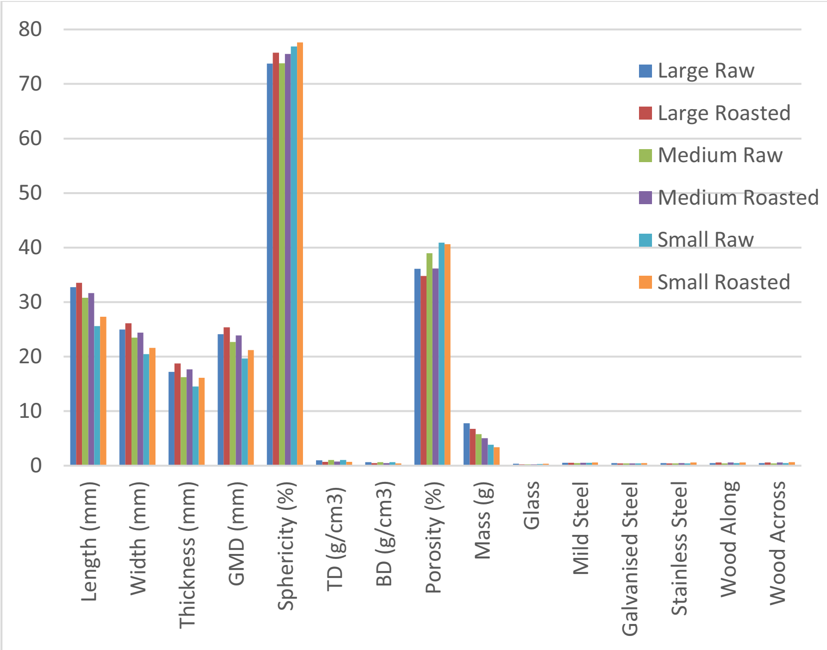

Fig. 3 Effect of pre-treatment on the physical properties of cashew nut

The compression test was carried out to determine the mechanical properties of cashew nut which include rupture force, energy absorbed during the rupture, deformation at rupture point and young modulus of the nut on three major direction of loadings (transverse, longitudinal and lateral). The results for the compression test is presented in Table 3. The rupture force decreases with decrease in nut size for the three loading directions, however the transverse loading requires higher force than longitudinal and lateral loading for the three nut sizes. This indicates that the larger nuts may require higher force to fracture than the smaller nuts, as it was also observed in sunflower seeds [16] and Jatropha curcas seed [17].

For the large and medium size nuts, the highest rupture energy was needed in transverse loading direction, followed by lateral loading direction. However, for the three nut sizes, longitudinal loading requires the least rupture energy. Similar result was reported by Ojolo and Ogunsina [18], however, it was not reported for different loading directions.

The compression along the longitudinal direction has the least deformation for the three nut sizes. This indicates that the nuts need lower compression in this direction to rupture. For the three nut sizes, the highest Young Modulus was exhibited in longitudinal loading direction, followed by transverse loading direction.

Table 3 Mechanical properties of the roasted cashew nuts

			LARGE		
Compressive load	**N**	**Force (N)**	**Energy at Yield (N.m)**	**Deformation (mm)**	**Young modulus (N/mm²)**
Lateral	60	345.12(119.4)	1.27(0.58)	7.17(1.86)	1724.44(980.17)
Longitudinal	60	362.44(139.60)	0.86(0.75)	4.72(3.39)	3654.28(1367.89)
Transverse	60	527.14(247.18)	2.07(1.17)	7.78(1.95)	2125.44(714.38)
			MEDIUM		
Compressive load	**N**	**Force (N)**	**Energy at Yield (N.m)**	**Deformation (mm)**	**Young modulus (N/mm²)**
Lateral	60	278.03(105.90)	1.09(0.49)	7.81(1.68)	1421.86(327.06)
Longitudinal	60	276.48(142.14)	0.69(0.39)	5.05(1.40)	3247.61(1016.19)
Transverse	60	379.31(216.03)	1.43(0.87)	7.56(1.75)	1905.56(442.11)
			SMALL		
Compressive load	**N**	**Force (N)**	**Energy at Yield (N.m)**	**Deformation (mm)**	**Young modulus (N/mm²)**
Lateral	60	273.69(91.87)	0.98(0.42)	7.03(1.62)	1385.08(384.23)
Longitudinal	60	175.18(120.79)	0.40(0.29)	4.74(0.92)	2842.90(1546.29)
Transverse	60	285.42(161.94)	0.88(0.55)	6.33(1.85)	1878.27(541.90)

4. Conclusions

1. The Physical properties of cashew nut was affected by pre-treatment by roasting in hot oil.
2. The dimensions of dry cashew nut increased with roasting and decreased in weight.
3. The rupture force increases with increase in nut size and this was found to be highest among the three directions of loadings when the nuts were loaded transversely. This finding will be useful in the development of shelling equipment for cashew nuts.

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